Analysis and Modeling of Surfzone Turbulence and Bubbles

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LONG-TERM GOALS

Turbulence in the surfzone and nearshore mixes momentum vertically, transmits stress to the sea bed, influences the structure of the cross- and alongshore currents, and controls the suspension of sediment from the sea bed. In many coastal and shelf environments, the sea-bed is the primary source of turbulence due to bottom induced shear. In the surfzone, the breaking-wave generated turbulence likely dominates over bottom generated turbulence. However, the dynamics of turbulence in the nearshore and surfzone under breaking waves is poorly understood.

Realistic three-dimensional simulations of surfzone hydrodynamics and sediment transport, which are currently being attempted, for example, in the recent nearshore NOPP project, will not be possible without at least a rudimentary understanding of breaking-induced turbulence dynamics. Long term goals include addressing some of the unresolved science issues through analysis and modeling of existing field measurements to quantify turbulence dynamics. This will significantly improve both circulation and sediment transport modeling.

OBJECTIVES

Understanding and accurately modeling the three dimensional nearshore circulation and sediment transport are goals of the ONR Coastal Geosciences Program. The vertical structure of the circulation and sediment suspension are a strong functions of nearshore turbulence. Increased understanding of turbulence in this region and the development of turbulence models for use in circulation and sediment transport models will greatly aid in achieving ONR Coastal Geosciences program goals.

Unresolved science issues are being addressed by further analysis and modeling of existing nearshore turbulence observations. The specific objectives over the past year include:

- Develop and test new methodologies for estimating turbulent dissipation and Reynolds stresses in wave dominated environments (completed).
- Develop and test coupled turbulence and single gas component bubble model (completed)
- Test a local balance for the turbulent kinetic energy at multiple vertical locations (completed)
- Test nearshore depth-scalings for turbulent dissipation (ongoing)
- Perform model-data comparisons using the turbulence and bubble model developed by the PI (ongoing).

Attainment of these objectives will contribute significantly to furthering the knowledge of surfzone and nearshore processes, and will move us toward the long term scientific goal of understanding

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14. ABSTRACT
The central goal is to integrate scientific resources and understanding so as to enable rapid and effective response to episodic natural or accidental hazards, such as severe storms, harmful algal blooms or toxic spills as well as potential terrorist threats. At the same time, it is intended that by establishing a robust environmental monitoring system in the lower Chesapeake Bay that provides long time series of flows, waves, water levels, water quality and water borne pollutants, pathogens and toxins, we will gain new understandings of complex phenomena while providing operational users with a valuable source of timely information relevant to safety and environmental stewardship. For addressing specific Navy needs, we also aim to provide the Navy with a portable suite of sensors, models and informatics techniques for detection, diagnosis, and predictions of manmade and natural water-borne hazards and threats, including intrusions, water-borne pollutants, pathogens and toxins in ports, bays and littoral waters.

15. SUBJECT TERMS

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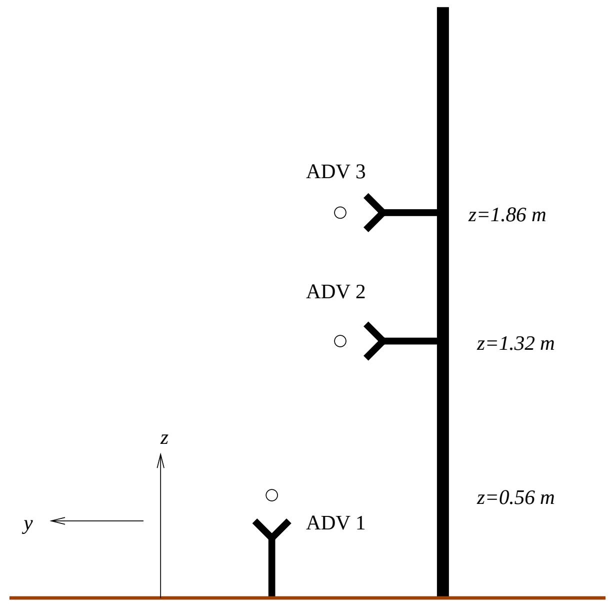

Figure 1: Schematic of the ADV locations. The view is toward offshore (+*x*), and the vertical *z* and alongshore *y* coordinates are indicated. ADV 1 is upward looking. The vertical location of the ADV sensing volumes (indicated by the small circle) are given.

nearshore circulation and sediment transport processes. These scientific goals are of societal significance because of the economic and recreational importance of the nation's beaches.

APPROACH

The model development (programming) and testing work is being done by the PI (Feddersen), as well as the model simulations and model-data comparisons. The basis of the coupled turbulence-bubble model is a standard k-ϵ model (*Rodi*, 1987) augmented with a wave-breaking turbulence source terms in an approach similar to that used for open-ocean wave breaking (*Craig and Banner*, 1994), but with the time-dependence of breaking retained. The model is described in detail in *Feddersen and Trowbridge* (2005).

The ongoing field data analysis is being done by the PI in collaboration with John Trowbridge of the Woods Hole Oceanographic Institution. The field campaign consisted of a main instrumented frame was deployed for 2 weeks at the U.S. Army Corps of Engineers Field Research Facility (FRF) at Duck N.C. in approximately 3.2 m mean water depth with the variable tides and wave heights (Fig. 1). At this depth, there was white-capping wave breaking but no depth-limited wave breaking. The main frame was instrumented with a vertical array spanning most of the water column of 3 ADV (Acoustic Doppler Velocimeter) and 4 conductivity cells to measure velocity and void fraction respectively. The void fraction measurements were meant to study bubble dynamics, however the sensors had significant noise problems and did not return any useful data. These measurements of the vertical structure of turbulence in the nearshore are unique and had not before been attempted in the nearshore region.

Field data analysis includes estimating the dissipation from the ADVs, using the frozen turbulence hypothesis and the inertial-dissipation technique (*Trowbridge and Elgar*, 2001). The vertically separated ADVs were used to infer the turbulent momentum fluxes, *i.e.*, (*e.g.*, *Feddersen and Williams*, 2005) that are part of the shear production term in the TKE dynamics.

WORK COMPLETED

- Completed testing of single-gas component bubble model
- Test turbulence component of the model with surfzone field observations. Paper (*Feddersen and Trowbridge*, 2005) in press at *J. Phys. Oceangr.*
- Developed and tested new methodology for estimation turbulence dissipation in wave dominated environments.
- Developed and tested new methodology for estimating Reynolds stresses in wave dominated environment. Manuscript (*Feddersen and Williams*, 2005) has been submitted to *J. Atmos. Oceanic Tech.*

RESULTS

Surfzone Turbulence Modeling

The newly surfzone/nearshore turbulence model is able to reproduce the observed non-dimensionalized turbulence dissipation $\epsilon/(g^3h)^{1/2}$ from three different data sets. The nondimensionalization of dissipation collapses the three data sets which come from different beaches and wave conditions (*Feddersen and Trowbridge*, 2005).

Estimating Reynolds Stresses

An important component of testing a turbulence model is developing field estimates of the Reynolds stress component $\overline{v'w'}$. As is discussed in *Trowbridge* (1998), estimation of $\overline{v'w'}$ in surface gravity wave dominated environments requires special methods. *Trowbridge* (1998) developed a $\overline{v'w'}$ estimation method using two current meters and tested it near the bed with two horizontally separated current meters (*Trowbridge*, 1998; *Trowbridge and Elgar*, 2001). *Shaw and Trowbridge* (2001) developed another method for vertically separated sensors with weak wave conditions near the bed off of the continental shelf. However, for the vertical ADV array (Fig. 1), a new $\overline{v'w'}$ estimation method had to be developed, because of problems with the other methods. The *Trowbridge* (1998) method has significant wave bias problems (not shown). The *Shaw and Trowbridge* (2001) method $\overline{v'w'}$ were better but often failed a test of the integrated velocity cospectrum. The new method, described in *Feddersen and Williams* (2005), is able to reproduce a constant stress layer (*i.e.*, vertically uniform $\overline{v'w'}$) in the wind-driven nearshore environment (Fig. 2).

Vertical Structure of Turbulent Dissipation in the Nearshore

The dissipation of turbulent kinetic energy (ϵ) is estimated with a new method (*Feddersen*, 2005) at each of the ADVs (Fig. 1). The mean plus the first EOF captures the majority (91%) of the ϵ variability. The observed ϵ has a maximum at the uppermost ADV, a minimum at the middle ADV,

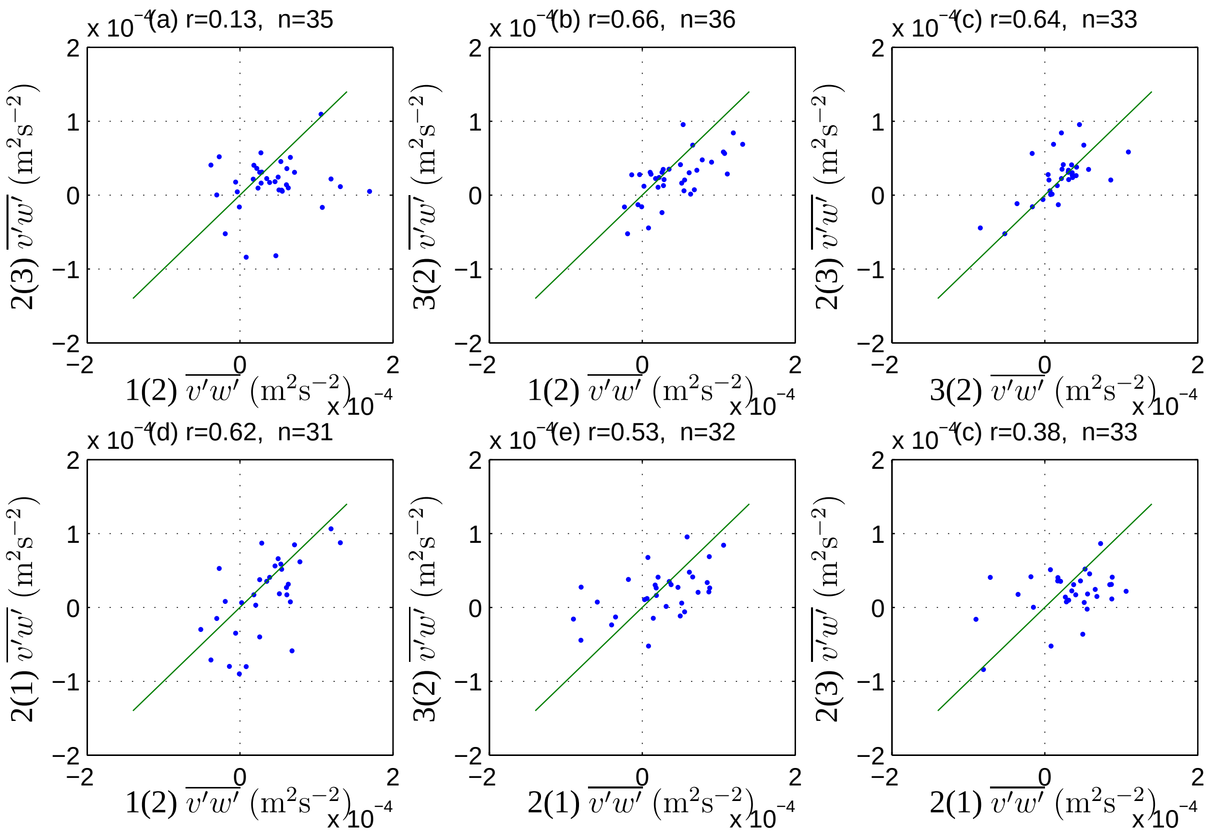

Figure 2: Inter-sensor comparison of *Feddersen and Williams* (2005) estimated $\overline{v'w'}$ for all combinations of vertical location. The correlations and number of good colocated estimates are given.

and another maximum but less than ADV 3, at the bottom (Fig. 3). This is consistent with surface generated turbulence due to wind-induced wave-whitecapping influencing ADV 3 and near-bed generated turbulence influencing ADV 1 (see for example *Feddersen and Trowbridge*, 2005).

Further demonstrating that the increased surface ϵ is not due to surfzone depth-limited wave breaking, the ϵ observations are scaled with a surfzone dissipation scaling (*Feddersen and Trowbridge*, 2005) giving the non-dimensional $\epsilon/(g^3h)^{1/2}$. At the same relative locations in the water column (Fig. 4), these values were much less that other scaled surfzone $\epsilon/(g^3h)^{1/2}$ (*George et al.*, 1994; *Bryan et al.*, 2003). Another process is giving the increased near surface ϵ.

Wind-induced wave whitecapping is likely that process. In a deep lake, *Terray et al.* (1996) found increased ϵ near the surface that scaled as

$$\epsilon H_{\rm sig}/(\alpha u_*^3) = 0.3(z'/H_{\rm sig})^{-2} \tag{1}$$

where z' is the distance from the surface, u_* is the friction velocity and α is a constant. This implies that white-capping was inputing turbulence at the surface which diffuses downward resulting in enhanced ϵ relative to law of the wall scaling. The top two ADVs follow this deep-water scaling (Fig. 5a,b). This demonstrates that the processes just offshore of the surfzone that result in increased near surface dissipation are the same wind-induced white-capping wave breaking as in

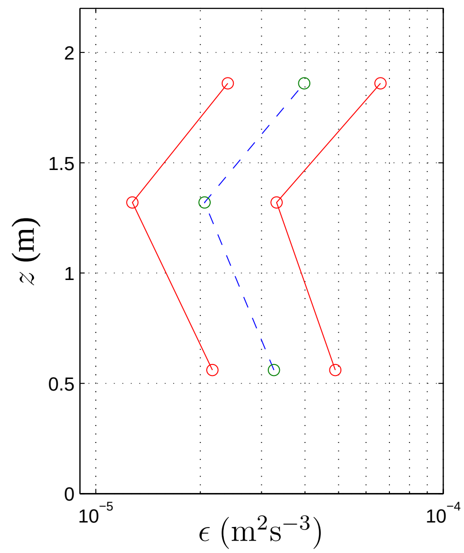

Figure 3: Vertical structure of the log-eof ϵ: mean (dashed) and mean $\pm$ first EOF (solid).

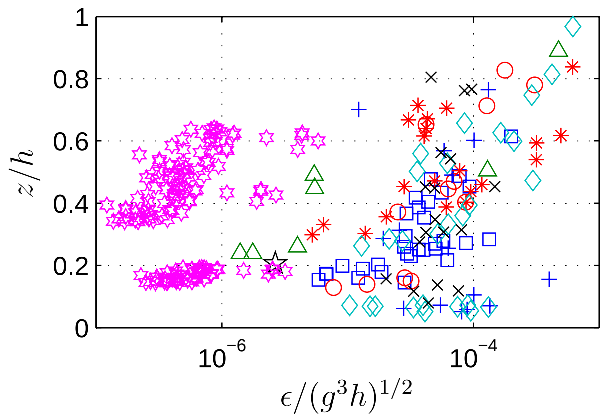

Figure 4: Surfzone scaled dissipation $\epsilon/(g^3h)^{1/2}$ as a function of normalized depth z/h. The magenta stars represent the observations reported here. The black star is the strongest dissipation observation of *Trowbridge and Elgar* (2001). The remaining symbols are the surfzone observations of*George et al.* (1994) and *Bryan et al.* (2003).

the deep water (*e.g.*, Anis and Moum, 1995; *Terray et al.*, 1996; *Drennan et al.*, 1996). However the near bed ADV does not follow this scaling and is likely influenced by bottom boundary layer processes.

IMPACT/APPLICATIONS

Potential impacts include vastly improved nearshore circulation and sediment transport modeling through the increased understanding of nearshore turbulence.

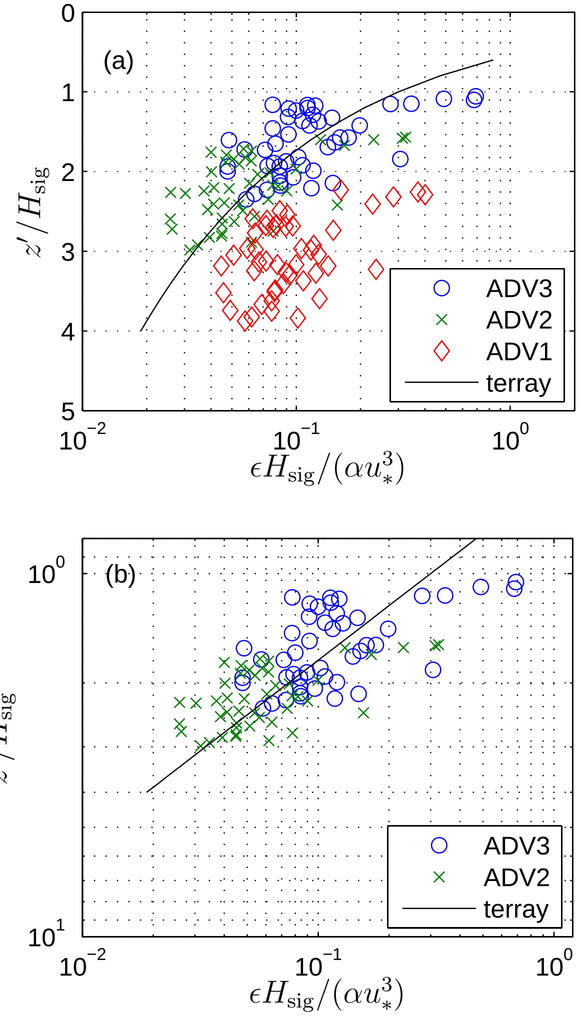

Figure 5: (a) Wave-scaled $\epsilon H_{\rm sig}/(\alpha u_*^3)$ versus wave-normalized depth $z'/H_{\rm sig}$. (b) log-log plot of the same. The black curve in (a,b) is the *Terray et al.* (1996) scaling of $\epsilon H_{\rm sig}/(\alpha u_*^3) = 0.3(z/H_{\rm sig})^{-2}$.

RELATED PROJECTS

There are no active related projects.

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